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JAMES BOYD, DIRECTOR

INFORMATION CIRCULAR

HAZARDS OF BLACK BLASTING POWDER IN UNDERGROUND COAL MINING

BY

D. HARRINGTON AND R. G. WARNCKE

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

HAZARDS OF BLACK BLASTING POWDER IN UNDERGROUND COAL MINING[1]

By D. Harrington[2] and R. G. Warncke[3]

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INTRODUCTION

The use of black blasting powder as an explosive in coal mines has long been recognized as hazardous and has been responsible for many of the worst disasters in American coal mines. One of the most pressing of the numerous problems confronting the Bureau of Mines upon its creation in 1910 was to determine methods that would lessen the hazards created by the use of explosives in coal mines. The Bureau continued the study begun by the Technologic Branch of the Geological Survey as to the nature of explosives and made numerous tests to determine types of explosives suitable for blasting in coal mines. The Bureau has tested and approved hundreds of types of explosives and has disseminated information on methods and conditions for use underground to make them permissible as to safety. The Bureau of Mines has encouraged the use of permissible explosives for coal-mine blasting, and its experts both in the laboratory and in the field believe that the use of black blasting powder in any form (granular or pellet) is hazardous in any underground coal mine. Despite the information published at various times and in numerous ways and the general knowledge of the hazards that the use of black blasting powder in any form creates in the blasting of coal, the coal mines in the United States, during 1947 used approximately 34 million pounds of black blasting powder (granular or pellet), or approximately 11.8 percent of the total quantity of explosives used by the coal-mining industry.

Many coal mines of the United States, for various and sundry reasons, probably will continue the use of black blasting powder, and this circular has been written for the benefit of such users, not that any suggested method or methods will make the use of this explosive safe, but it has been found that methods and conditions of use of black blasting powder can be improved so as to lessen, though not eliminate, the hazards created by its use.

COMPARISON OF THE CHARACTERISTIC ACTION OF BLACK BLASTING POWDER WITH OTHER EXPLOSIVES USED IN COAL MINES

Two forms of black blasting powder are now used for blasting purposes in coal mines in the United States - granular and pellet. Granular, the oldest form, is a loose, free-running, definitely grained powder, which either is used loose or made into relatively loose cartridges, whereas pellet powder is similar in composition to the granular type, but the powder is pressed into cylindrical pellets. Pellet powder was first introduced about 1925 and rapidly gained favor with some sections of the coal-mining industry, largely because it is considered a "safe powder"; it was supposed to be much safer than granular powder. During 1947, approximately 3-1/2 times as much pellet powder was sold to the coal-mining industry as granular, as 77.3 percent, or 26,219,575 pounds, of a total of 33,904,900 pounds of black blasting powder sold was of the pellet type. As the chemical composition of pellet and granular black blasting powder is basically the same and the effects are similar, in the following discussion black blasting powder refers to both the pellet and the granular form.

Black blasting powders are classified as low explosives and are deflagrating explosives, in that they burn progressively over a relatively sustained

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period of time in comparison with high explosives, which decompose almost instantly. The process of changing black blasting powder from a solid to a gaseous state is termed "the rate of burning" and has been found to be about 1,500 feet a second, whereas the conversion of permissible explosives and dynamite from a solid to a gaseous state is termed the "rate of detonation" and varies from 4,700 to 15,000 feet a second, each brand having its own well-defined rate; the rate for 40-percent dynamite is about 15,000 feet a second. Thus, the action of permissible explosives is about 3 to 10 times quicker than black blasting powder, whereas dynamites are about 10 times quicker. The theoretical unit pressure produced in the conversion of black blasting powder from a solid to a gaseous state is approximately 70,000 pounds, or 35 tons per square inch, whereas that of permissible explosives ranges from 70,000 to 125,000 pounds, or 35 to 62-1/2 tons per square inch; dynamite produces a unit pressure of over 115,000 pounds, or 57-1/2 tons per square inch. The relatively slow action and small unit pressure developed by black blasting powder has a heaving action that is usually productive of a maximum percentage of lump coal, whereas the extreme quickness and heavy unit pressure developed by dynamite is responsible for a shattering effect upon coal, which results in production of a product having a relatively large percentage of the fine sizes. Permissible explosives with a fast rate of detonation may approximate the properties of dynamite, except the unit pressure developed is somewhat less than that of dynamite; no permissible explosive has yet been placed on the market that has the heaving, lump-coal action of black blasting powder, although some approach it. The characteristic action of the comparatively slow-burning black blasting powder, with its heaving or wedging effect to break the coal into lumps in comparison with the quick shattering effect of permissibles, has had a tendency to make many coal-mining operators hesitate to adopt permissible explosives. However, in recent years the manufacturers of explosives have developed permissible explosives with a unit pressure approximately that of black blasting powder, with a rate of detonation about three times the burning rate of black blasting powder. These explosives, when properly used, can, if carefully manipulated, blast satisfactory grades and percentages of large-size coal, comparing relatively well with that blasted by black blasting powder.

Highly detrimental characteristics of black blasting powder, distinctly different from permissible explosives, are the length and duration of the flame following ignition. The duration of the flame of black blasting powder is 1,500 to 3,500 times that of permissible explosives or dynamite. Experiments have shown that when black blasting powder is ignited, the flame lasts 1-1/2 seconds; whereas, when permissibles or dynamite are detonated, the flame endures for only about three-ten-thousandths of a second. Similarly, the length of the flame for black blasting powder is two to four times greater than that of permissible explosives, and about twice that of dynamite.

In blasting, the theoretical flame temperature of black blasting powder and permissible explosives is nearly the same; however, black blasting powder has a slightly higher temperature whereas dynamite has virtually double the heat intensity of black blasting powder or permissibles. The flame temperatures of black blasting powder or dynamite are intense enough to

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ignite flammable mixtures of gas or coal dust in suspension in air. Bureau of Mines tests have shown that although dynamites and permissible explosives have essentially the same time duration of flame, the much higher flame temperature of dynamite causes ignition in nearly all tests in a gas or coal-dust mixture in air. Permissibles are detonated without ignition, but black blasting powder, which has a flame temperature nearly that of permissible explosives, causes ignition in every instance, owing to its extremely long flame duration as well as greater flame length.

The ease of ignition and the promptness with which black blasting powder explodes differ greatly from those of permissible explosives and dynamite. Black blasting powder is easily ignited by sparks, flames, or other sources of heat and explodes promptly when ignited, whereas permissible explosives are not easily ignited by any of these heat sources and do not burn vigorously nor explode promptly when ignited. This ready flammability of black blasting powder has been the cause of innumerable accidents both underground and on the surface.

DECLINE IN THE USE OF BLACK BLASTING POWDER IN COAL MINES

In 1947, coal mining required the use of 286 million pounds of explosives, or 46 percent of the commercial explosives produced and sold in the United States. These explosives were used in mining approximately 676 million tons of bituminous coal and anthracite, with the exception of about 9 percent of the bituminous coal, which was mined by blasting devices other than explosives. The percentage of explosives used in coal mines gradually increased during the war years; in 1942, 1943, 1944, and 1945, 35.3, 39.7, 47, and 48 percent, respectively, of the total quantity of commercial explosives manufactured and sold in this country were used in coal mining. Of the three types of explosives used in coal mines - high explosives, permissible explosives, and black blasting powder - the latter two are used almost exclusively in coal mines. Less than 1 percent of permissible explosives manufactured in 1947 was used in other than coal mines, whereas for the past few years 91 to 94 percent of the black blasting powder produced has been for coal-mine use.

Granular black blasting powder and dynamites were used exclusively in coal mines before 1902, at which time the first short-flame explosives were introduced with a view to decreasing the gas-ignition hazards attending the firing of shots. Seven years later, the first permissible explosives were introduced, and in 1909 about 4 percent of the total quantity of explosives used was of the permissible type. The percentage of black blasting powder used in coal mines gradually decreased from 1909, when more than 90 percent of all explosives used was black blasting powder, to 11.8 percent in 1947 for all coal mines.

The downward trend of the use of black blasting powder as a coal-mine explosive is shown in table 1, where the amounts of explosives used for blasting are given in percentages.

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TABLE 1. - Percentage of different explosives used in coal mining

Year	Bituminous			Anthracite		
	Black powder	Permissibles	High explosives	Black powder	Permissibles	High explosives
1917	84.0	10.9	5.1	60.4	12.3	27.3
1920	78.3	14.5	7.2	45.4	16.7	37.9
1925	70.8	23.7	5.5	29.9	28.3	41.8
1930	63.3	30.9	5.3	26.0	32.8	41.2
1931	66.2	28.8	5.0	24.8	37.7	37.5
1932	68.1	25.5	6.4	23.3	40.8	35.9
1933	67.3	25.9	6.8	17.6	42.9	39.2
1934	65.0	27.9	7.1	17.4	40.4	42.2
1935	62.6	28.6	8.8	19.0	39.5	41.5
1936	60.5	30.8	8.7	18.9	39.9	41.2
1937	52.7	35.5	11.8	17.4	38.9	43.7
1938	51.3	35.2	13.5	15.9	42.4	41.7
1939	49.9	38.8	11.8	15.6	44.0	40.4
1940	46.1	41.9	12.0	14.8	42.2	43.0
1941	39.1	44.3	16.6	12.2	39.3	48.5
1942	33.9	49.5	16.6	11.1	40.0	48.9
1943	26.8	52.0	21.2	8.4	35.7	55.9
1944	21.1	50.0	28.9	7.1	32.5	60.4
1945	13.3	47.4	34.3	5.7	28.2	66.1
1946	16.4	45.6	37.0	4.8	28.7	66.5
1947	14.1	47.2	38.7	4.3	26.5	69.2

In bituminous-coal mining, black blasting powder shows a slow but steady decline from 1917 until 1930, when for a few years it increased and did not resume its downward trend until 1935. This was during the depression years, when many large operations that used permissible explosives were idle or had a curtailed production, whereas many of the smaller mines, most of which use black blasting powder, continued operation. However, since then the decline in the use of black blasting powder has been rapid, particularly since 1940.

The decrease in the use of black blasting powder has been more rapid in anthracite than in bituminous-coal mining. In anthracite mining the decrease was from 60 percent in 1917 to 4.3 percent in 1947, whereas in bituminous-coal mining the percentages were from 84.0 to 14.1 percent during the same period. It is interesting to note that the quantity of black blasting powder used in anthracite mining was first exceeded by permissible explosives in 1926, whereas in bituminous-coal mining it was not until 1941, 15 years later, that more permissibles than black blasting powder were used.

The 4.3 percent of black blasting powder used in anthracite mining during 1947 represents 2,783,080 pounds, whereas the 14.1 percent in bituminous-coal mining represents 31,121,820 pounds, a total of 33,904,900 pounds, which is a marked decrease from 1917, when all mining used 235,750,300 pounds of black blasting powder, of which 199,996,775 pounds were used in bituminous-coal mining.

Although the figures in table 1, which includes underground and surface mining, show a gradual and steady decrease in the use of black blasting

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powder, they do not reflect a corresponding increase in the use of permissible explosives, as both permissibles and high explosives are used to replace black blasting powder. The increase in the use of high explosives other than permissibles since 1940 results from the increase in rock work in the development of new mines and from the rapid strides made in strip mining of bituminous coal, which increased from 43 million tons in 1940 to approximately 135 millions in 1947. This also applies to anthracite mining, in which much of the development work is through rock requiring high explosives, which are also used in strippings from which the tonnage nearly doubled between 1940 and 1947, increasing from 6,352,700 tons to 12,603,545 tons.

The gradual decline in the use of black blasting powder is due primarily to the fact that permissible explosives have been developed that give the best combination of safety and efficiency in the blasting of coal up to this time. The superiority in safety of permissible explosives over black blasting powder for blasting in coal mines was recognized early, and at the present time, particularly within the past 15 years, most coal-mining men and coal-mining safety engineers have condemned as unsafe the use of black blasting powder in coal mines. The Federal Bureau of Mines, from its studies and investigations of many disasters, took the lead in recommending that permissible explosives, fired electrically, should be the only explosive used in any coal mine, and the Bureau engineers have consistently opposed the use of black blasting powder because of its many inherent hazards and ease of misuse in methods of storing, handling, and firing. Several States have enacted laws regarding the use of black blasting powder in coal mines; although only one State (Utah) prohibited its use, some other States permit it to be used only under certain conditions, and several States prohibit its use in gassy mines. Some of the manufacturers of explosives are opposed to the use of black blasting powder in gassy mines, as stated on page 1 of Blasters' Handbook (11th edition) by duPont: "Black powders cannot be used, however, in coal mining where mine gas or dry coal dust is present in hazardous quantities, under such conditions permissible dynamite should always be used."

Before the introduction of permissible explosives, black blasting powder was the only practicable coal-mining explosive used in the United States. Although its use was early recognized as hazardous, the many rules and regulations adopted for safety had little effect upon the reduction of fatalities resulting from blasting accidents and explosions ignited by explosives. There was no noticeable reduction in this class of fatalities until after decrease in the use of black blasting powder had become definite. The following table gives the blasting fatalities in bituminous-coal and anthracite mines:

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TABLE 2. - Fatalities from explosives (underground only)

Year	Directly due to explosives			Gas and dust explosions caused by blasting or explosives			Total
	Anthracite	Bituminous	Total	Anthracite	Bituminous	Total	All causes
1917	55	55	110	-	-	26	136
1920	49	78	127	-	-	48	175
1925	53	49	102	-	-	93	195
1930	31	47	78	9	1	10	88
1931	25	15	40	0	1	1	41
1932	15	21	36	0	38	38	74
1933	10	24	34	0	0	0	34
1934	15	21	36	1	0	1	37
1935	19	31	50	0	0	0	50
1936	20	31	51	1	0	1	52
1937	14	31	45	1	-	1	46
1938	11	23	34	1	50	51	85
1939	17	15	32	1	28	29	61
1940	8	28	36	1	73	74	110
1941	12	24	36	1	3	4	40
1942	13	16	39	0	2	2	41
1943	9	27	36	0	1	1	37
1944	16	29	35	0	1	1	36
1945	9	24	33	0	14	14	47
1946	8	12	24	1	15	16	40
1947[1/]	8	21	29	0	120	120	149

1/ Preliminary.

This table shows that underground fatalities caused by explosives have decreased materially in recent years, following closely reduction in the use of black blasting powder, as shown in table 1, and with it many hazardous blasting practices, including the firing of shots with fuse and sulfur squibs.

Reduction in the number of fatalities from gas and dust explosions caused by explosives or blasting is due largely to the increased use of permissible explosives, particularly in dangerous mines or in hazardous dusty or gassy sections of mines. Since 1940, nearly all the coal-mine explosions due to blasting were initiated by black blasting powder. The great loss of life in 1940 was largely the result of one disaster in which a blown-out shot of black blasting powder initiated an explosion that took 72 lives. The other deaths from blasting in bituminous-coal mines resulted from the use of black blasting powder in small mines. Fortunately, the loss of life was small in each instance, as the explosions occurred on the off-shift while only shot firers were in the mine or while only a few men were at work. Although the loss of life was small in each instance, there is always the potential hazard of a widespread explosion. Many explosions due to black blasting powder have been reported in which no loss of life was involved, and most of these occurred in small mines after the shot firer had reached the surface, and in many instances the mine was badly damaged.

Explosions from the use of black blasting powder appear to be increasing in number in the past few years, as more such explosions were reported during

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the fiscal year of 1945 than for any of the previous 16 years. Four of them occurred in one mining district, while one, which caused nine deaths, resulted either from dynamite (which is more hazardous than permissible explosives) or the use of permissible explosives in a nonpermissible manner. In January 1946 an unconfined charge of dynamite near the bottom of a shaft initiated a dust explosion that took 12 lives, injured many persons, and wrecked the surface structures at or near the shaft. Fortunately, the mine had been well rock-dusted, which prevented the explosion from spreading and probably saved the 200 or more men in the mine.

REASONS FOR USING BLACK BLASTING POWDER

The officials of coal mines in which approximately 34 million pounds of black blasting powder was used during 1947 have many definite and varied reasons for continuing its use; although some of these reasons may seem unsound to many mining safety engineers, nevertheless many of these companies can more or less justify its use.

The principal reason given by most users of black blasting powder is that they believe it permits production of a greater percentage of lump coal or lumps of greater solidity and less slack coal than is produced by other types of explosives. These companies, some large but most of them smaller operations, depend mainly on the domestic trade that requires the lump and larger sizes, and there is little or no demand for small sizes and slack coal. These sizes have little or no marketable value to the operators, and in some instances they must be handled at a dead loss. The coal in these mines is usually shot off the solid, as it is economically impossible to purchase and install cutting machines in many of these operations; furthermore, power is often unavailable either at or near the mine. Numerous mines use black blasting powder in the production of lump coal, inasmuch as other types of explosives cannot perform efficiently when used for blasting off the solid, particularly in producing broken coal of marketable size and solidity. Often excess production of the fine sizes of coal means the difference between continued operation or closing of the mine; thus, many mines justify the continuance of the use of black blasting powder.

This is well-illustrated in a test recently conducted at a western coal mine. The management of the property desired to change from blasting with pellet powder to permissible explosives and had a technical representative of one of the explosives manufacturers conduct tests in different sections of the mine for 2 weeks. All coal is shot off the solid by drilling crews that drill, charge, and fire all shots, and the coal is loaded mechanically. Several grades of permissible explosives with wide ranges of velocities and strengths were used; the amounts of charges varied, and various methods of drilling holes were tried, but no appreciable degree of success was obtained by any grade of permissible explosives or methods in rolling the coal from the face and making it easily accessible for mechanical loading. The cost per ton of blasting with permissible explosives compared favorably with the cost with black blasting powder, but the grade and size of lump coal were not comparable; it was also observed that the quantity of fine coal dust was increased. The explosives representative believed that it would be necessary

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to shear the coal to obtain a satisfactory grade of lump with permissible explosives. After the test, the mine operator stated that he would be willing to discontinue the use of black blasting powder if a substitute could be found that would do the work as well, but that he could not sacrifice his market for lump coal; this would happen if he used the permissibles now available.

This illustrates the attitude of many operators; however, in this instance, where power is available and where the coal is drilled and loaded mechanically, the operator could and should, in the interest of safety, have the coal undercut or sheared when using permissible explosives.

Many mines that undercut or shear the coal continue the use of black blasting powder, believing that it alone can produce a good grade of lump coal. There is little justification for this belief, as it has been proved by practice and experiments that when the coal is cut or sheared grades of permissible explosives are now available that can produce a grade of lump coal comparable to that obtained with black blasting powder. The operators of these mines should further investigate the use of permissible explosives as a safety measure for protecting both the employees and the mine property.

One reason advanced by some companies for the continued use of black blasting powder is the difference in cost of explosives and methods of firing. Generally, this is based upon difference in cost per shot by black blasting powder fired with fuse and cost per shot by permissible explosives fired electrically. On this basis, the cost is in favor of black blasting powder, and the cost of firing shots with fuse is somewhat less than with electric blasting. Also, in solid shooting, where drilling and spacing of holes are the same for blasting with permissible explosives as with black blasting powder, the cost is likely to be in favor of the latter; but if the holes are spaced and drilled differently, the cost per ton of coal produced by permissibles compares favorably with the cost of black blasting powder and in many instances is in favor of permissibles.

This is well-illustrated by a report in 1942 on the cost of blasting, per ton of coal, with different explosives in the anthracite fields of Pennsylvania, where virtually all the underground production is from solid shooting. The costs of blasting per ton of coal were as follows:

	Per ton
Where only black blasting powder was used	$ 0.07909
Where only pellet powder was used	0.08149
Where only permissible explosives were used	0.08497

These figures indicate that the cost of blasting with permissibles is only a fraction of a cent more than with black blasting powder; this is the average cost for the whole district; hence, it is apparent that in some mines the cost of using permissible explosives is much less than when black blasting powder is used.

Figures are not available for the cost per ton in bituminous-coal mines on the same basis as the above for anthracite mines, but there are numerous

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records that show a lowering of the cost per ton for blasting by permissible explosives after the coal was undercut, overcut, or sheared. There probably are many instances where coal is shot from the solid by black blasting powder instead of permissible explosives and the cost is less; however, the managers of mines in which the coal is undercut cannot justify their continued use of black blasting powder on the basis of cost alone, for it has been proved that the cost for blasting is the same or less when permissible explosives are used. This is because smaller quantities of permissible explosives are required to perform the amount of work done by black blasting powder.

Some coal beds and the overlying strata have physical characteristics, such as friability, that are adversely affected by quick-acting, shattering explosives such as permissibles. To mine friable coal beds successfully requires an explosive having a slow and heaving action that does not shatter the coal; black blasting powder works more successfully in this type of coal than other explosives.

There are still many mines (mostly hand-loading) in which the miner drills, charges, and fires the shots, and here black blasting powder is used because of the belief that it is easier to use and that a more thorough knowledge of drilling and use of explosives is required when blasting with permissible explosives. This is largely true, as the number of drill holes per face, the diameter of the hole, placing, inclination, etc., are all important when using permissible explosives. The slow action and heaving effect of black blasting powder extends over a considerable area, few holes are necessary, and the exact quantity of black blasting powder for the charge is not particularly essential; with permissible explosives, the quick action and generally high unit pressure give little opportunity for expansion of the gases within the material blasted, make necessary a greater degree of care in estimating the size of the charge, and probably require a greater number of holes to be drilled. While the full breaking effect of permissible explosives might be more difficult to obtain than that of black blasting powder, it is probable that these difficulties can be largely overcome if both management and miners are willing to accept the experiences of others or, preferably, by employing experienced shot firers to drill and fire all shots.

Some coal-mining companies continue to use black blasting powder because of exacting commitments or contracts with the employees that require explosives to be furnished at a specified cost. Although most of such contracts were made before the present grades of permissible explosives were available, little or no change has been made in the terms of the contract, with the result that black blasting powder is sold today essentially for the price it was sold for 20 to 30 years ago. Some of the companies using black blasting powder have well-organized safety departments and probably are cognizant of the hazards of black blasting powder, but contractual and possibly other conditions make it difficult to effect desirable changes in procedure.

Table 3 was prepared from Mineral Market Report 1555 and 1558; it shows the quantities of various types of explosives sold and the methods of producing coal in the various States and reveals some interesting information obtained where black blasting powder was used. Although the explosives listed in this table were sold to mining companies, some of them probably were used for purposes other than mining, such as construction or roadbuilding, but usually the quantity used for such purposes would constitute only a small part of the total.

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TABLE 3. - Explosives sold and production, bituminous-coal mines, 1946

State	Explosives sold in 1946, pounds				
	Black blasting powder				
	Granular	Pellet	Total	Permissible	High explosives
Alabama	56,950	963,750	1,020,700	5,640,250	2,164,124
Alaska	-	-	-	345,000	20,000
Arkansas	322,555	99,650	422,200	58,850	734,650
Colorado	19,100	170,600	189,700	759,425	176,850
Georgia	7,400	35,250	42,650	100	35,500
Illinois	1,555,600	5,478,200	7,033,800	9,703,825	5,457,533
Indiana	289,125	1,616,575	1,905,700	2,132,100	11,269,279
Iowa	189,525	646,300	835,825	3,200	334,500
Kansas	30,300	94,050	124,350	13,050	2,679,235
Kentucky	3,573,925	3,947,900	7,521,825	8,811,737	7,379,384
Maryland	43,300	140,100	183,400	284,800	31,069
Michigan	-	8,800	8,800	20,350	2,305
Missouri	506,225	241,275	747,500	14,400	3,829,065
Montana (bit.)	4,050	13,800	17,850	220,250	2,143,668
New Mexico	-	27,500	27,500	290,150	300
North Dakota (lig.)	118,200	332,550	450,750	105,850	142,800
Ohio	574,050	1,157,175	1,704,225	2,099,025	5,752,376
Oklahoma	276,225	552,750	828,975	92,100	1,219,775
Oregon	-	-	-	8,550	2,000
Pennsylvania	719,850	2,186,950	2,243,050	17,907,577	12,975,492
Tennessee	441,100	1,523,200	1,964,300	753,900	455,436
Texas (lig.)	500	-	500	-	11,800
Utah	-	-	-	1,988,475	9,900
Virginia	753,200	390,650	1,143,850	3,582,550	914,805
Washington	10,225	-	10,225	434,300	190,200
West Virginia	221,375	235,300	456,675	25,902,028	10,429,494
Wyoming	8,500	39,750	48,250	1,235,000	274,550

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TABLE 3. - Explosives sold and production, bituminous-coal mines, 1946 (Cont'd.)

State	Production, 1946, tons					
	Underground mining				Strip mining	Total production
	Hand mining	Solid shooting	Machine cutting	Total		
Alabama	155,750	3,234,607	10,977,735	14,368,152	1,815,146	16,183,298
Alaska	-	280,173	-	280,173	86,636	366,809
Arkansas	42,705	73,020	952,507	1,068,232	563,242	1,631,474
Colorado	774,586	191,126	4,792,773	5,758,485	155,023	5,913,508
Georgia	-	24,798	-	24,798	88,965	113,763
Illinois	204,764	1,886,365	46,215,638	48,306,767	15,161,818	63,468,585
Indiana	49,667	150,546	9,670,379	9,870,592	11,826,355	21,696,947
Iowa	60,109	521,434	575,797	1,157,300	630,833	1,788,133
Kansas	49,583	35,071	126,010	210,664	2,282,721	2,493,385
Kentucky	487,741	8,758,479	49,952,393	59,198,613	7,354,364	66,552,977
Maryland	825,392	-	619,423	1,444,815	557,730	2,002,545
Michigan	-	-	79,900	79,900	-	79,900
Missouri	28,373	24,007	339,514	391,894	3,340,921	3,732,815
Montana (bit.)	-	10,324	1,219,836	1,230,160	2,452,753	3,682,913
New Mexico	71,868	187,070	1,021,341	1,280,279	-	1,280,279
North Dakota (lig.)	-	33,875	393,231	427,106	2,127,576	2,554,682
Ohio	87,104	30,015	17,990,204	18,107,323	14,206,939	32,314,262
Oklahoma	3,098	64,276	907,512	974,886	1,672,494	2,647,380
Oregon	1,064	200	15,889	17,153	-	17,153
Pennsylvania	8,909,306	2,582,813	82,317,930	93,810,049	31,686,807	125,496,856
Tennessee	281,037	566,001	4,575,107	5,422,145	196,207	5,618,352
Texas (lig.)	-	-	-	-	55,978	55,978
Utah	6,708	259,242	5,728,063	5,994,013	-	5,994,013
Virginia	133,592	1,010,925	13,726,562	14,871,079	655,816	15,526,895
Washington	91,084	387,390	415,097	893,571	97,556	991,127
West Virginia	2,909,768	3,053,093	123,120,104	129,082,965	14,937,127	144,020,092
Wyoming	104,089	137,165	6,400,545	6,641,799	992,685	7,634,484

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A study of table 3 reveals that several States having large production of coal use more black blasting powder than permissibles. It many of these States the production of machine-mined coal greatly exceeds that from hand-mining and solid shooting, thus indicating that black blasting powder is used to a considerable extent for blasting machine-mined coal. Likewise, several States use very little black blasting powder while deriving a large quantity of their production from coal that is not machine-mined. No black blasting powder was purcheased during 1946 in the State of Utah by coal-mining companies, which produced nearly 6 million tons of coal.

West Virginia, with an underground production of 129 million tons of coal in 1946, used only 456,675 pounds of black blasting powder, whereas Pennsylvania, with an underground production of 94 million tons, used over 2 million pounds. Over 7-1/2 million pounds of black blasting powder, of which 3-1/2 million pounds was granular, was sold in Kentucky, where the underground production was more than 59 million tons. Machine-cut coal was 84 percent of the total underground production in Tennessee, yet more than twice as much black blasting powder as permissible explosives was sold. In 1946 Washington produced (largely from steeply pitching beds) about 43 percent of the total underground tonnage from solid shooting, but the amount of black blasting powder consumed was only about 0.2 percent of the total explosives used for all blasting.

Accidents Resulting from the Use of Black Blasting Powder

Hazards are involved in handling and using any type of explosives in coal mines. These hazards are present from the time the explosives are received and stored until they are finally consumed in a blast, but experience has shown that reasonable safeguards, precautions, and recognized safe practices in blasting will ordinarily minimize many of the hazards. However, black blasting powder has many physical characteristics, not found in other explosives, that make its use inherently unsafe. Some of these hazards cannot be overcome under some conditions by means of reasonable safeguards and precautions. Also, throughout the years many dangerous practices and abuses have accompanied the use of black blasting powder; this tends to increase or accentuate its hazards. Briefly, some of the dangerous practices in the use of explosives include solid shooting, firing with fuse or sulfur squibs, use of short fuse, use of dynamite and permissible explosives in the same hole, use of heavy charges of permissible explosives drilled on the solid and in a direction perpendicular to the face, and many other dangerous practices, including the use of combustible stemming or even no stemming.

The following accounts of accidents that have occurred in and around coal mines show the need for utmost care and precaution when handling and using black blasting powder. These accidents have occurred within the past 15 years, many within the past few years. To better illustrate the various hazards and the accidents likely to occur, they have been compiled under headings covering accidents that are somewhat similar:

1. Ease of ignition.
2. Electrical ignitions.
3. Fires caused by black blasting powder.
4. Gas and dust explosions.

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Unlike other explosives, black blasting powder is readily ignited by open flames and sparks, and this characteristic constitutes one of the greatest hazards in the storing, transportation, handling, and use of this type of explosive in or around coal mines, and has been the cause of numerous fatalities and injuries. Smoking or sparks from burning tobacco and matches probably have been the greatest causes of ignition, although the open or naked-flame lamp follows closely as a source of ignition. Many deaths have resulted from using a pick to puncture a hole in a powder keg when friction or frictional sparks ignited the black blasting powder. Friction or sparks from a metal-tipped tamping bar igniting loose powder in a borehole also have been the cause of many premature explosions that have taken many lives. Report of many accidents indicate that any highly heated object is likely to ignite black blasting powder, as shown in some of the following incidents.

Powder dust blowing against a heated stove was ignited. The powder need not be exposed to be ignited by excess heat, as there are records of unopened kegs being ignited by external heat such as is present during a gas or dust explosion or as in a recent incident where a burning machine cable, from which power had been cut off, ignited a keg of black blasting powder when the cable was pulled over the keg.

The greatest disaster from this cause occurred near the portal of an anthracite mine where 143 men were being transported into the mine on a 13-car man-trip hauled by a trolley locomotive. Twenty-four kegs of granular black blasting powder were distributed in the cars. Investigation of the accident indicated that an open light coming in contact with a keg of powder was responsible for the ignition. Ninety-two men were killed and forty-four were injured.

1. Five men were burned, four fatally, in a premature explosion of pellet powder in a gravel pit. A charge of 700 pounds of black pellet powder was to be set off in each wing of a coyote tunnel. The sticks of powder were being removed from the cases and "shucked" (paper wrappings removed) on the pit floor outside the tunnel when the explosion occurred. The cause of the ignition was not definitely determined, but it is believed that a hot spark or sparks from a steam shovel that was operating about 400 to 500 feet away fell into the exposed powder. This accident, although not at a coal mine, could readily have occurred at a coal mine.

2. The premature explosion of black pellet powder that was being loaded onto a supply truck as the night shift was preparing to enter the mine caused the death of one miner and seriously burned three others. A case of 75 sticks of pellet powder was being loaded onto the truck, which also contained 18 pieces of 7-foot fuse, a drill, a box of clay dummies, and some steel ties. Portions of three or four sticks of pellet powder, with the wrapper removed, were lying on top of the explosives box. One of the men near the truck was filling a carbide lamp, which, in attempting to light it or after it was lit, fell into the box containing the pellet powder.

3. A driller was fatally burned and another was severely burned as a result of a premature ignition of pellet powder. The drillers had completed

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drilling five holes; two bottom and two top holes had been charged, and it was while the last top hole was being charged that the ignition occurred. It was believed by some of the investigators that the charge was ignited by the flame of the carbide lamp the driller was wearing while placing explosives in the hole. Others believed that the driller's light ignited some gas that was forced out of the hole while inserting the charge, which in turn ignited the pellet powder.

About a year before this accident, two men were killed in this mine from an explosion of 50 pounds of pellet powder and 15 pounds of permissible explosives when the drill truck they were pushing struck a trolley wire that was reported to have fallen from its hangers.

This mine is recognized as gassy; even though carbide lights were used, nonpermissible electrical equipment was used at the face, the coal was undercut and loaded by track-mounted loading machines, and the mine was dry and dusty but not rock-dusted. Black pellet powder stemmed with coal cuttings and tamped with iron bars capped with Babbitt metal was used for blasting. The holes were drilled and charged during the shift but were fired at the end of the shift by shot firers after all other men were out of the mine.

4. The explosion of a keg of black blasting powder in a home caused the death of seven and serious injury to four members of a family. The father and two sons operated a small slope mine. The keg of powder that exploded was stored with other kegs in a chicken coop about 75 feet from the house, but the explosive had become damp and it was taken into the home to dry and placed about 5 or 6 feet from a hot stove. It is not known how the powder was ignited; however, it is known that two of the boys had carbide lamps on their caps, as they were preparing to go outside to do some work.

5. Six men, who were eating their lunch in a crosscut about 100 feet inby the drift mouth of a small coal mine, died from burns resulting from the explosion of a keg of black blasting powder. One of the men was preparing a cartridge when the explosion occurred; all were wearing carbide lights, and some probably were smoking. The coal in this mine was shot off the solid with black granular powder and squibs, and it was common practice to open the powder kegs with picks.

6. Two men were seriously burned, one of whom died later, from an explosion of granular black blasting powder. One of the men had borrowed a 10-pound lard can of powder the previous day and had returned it. They were both in a small one-room shack used as a mine office, in which was a stove that had become overheated. One man was pouring powder from the lard can into a powder jack. The door of the shack was open, and apparently a strong gust of wind blew some powder dust against the hot stove.

7. A fire destroyed the headframe, hoisting house, and tipple of a mine. This resulted in the death of two men in the mine. On the morning of the fire, a can of FFF black blasting powder was brought to the mine and stored in the hoist house. The hoist engine was a converted Ford, model A, 4-cylinder gasoline engine having the gas tank above it. Gasoline was supplied to the

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engine through a 1/4-inch copper tube. The powder was ignited by the heat thrown off from an egg-shaped stove. The explosion disconnected the tube from the tank and allowed the gasoline to spread the flame. There were three men in the mine, but only one was able to climb the 67-foot shaft and reach the surface.

8. A shot firer of a drilling crew was fatally burned by the explosion of a keg of granular black blasting powder on a drilling truck, which was situated about 12 feet from the face of the room. He was sitting on the truck and, while making cartridges, attempted to light his pipe, when a spark from the match head flew into a keg half full of black blasting powder, which was on the truck. The truck was well-insulated and contained a new electric cable, which recently had been installed on the reel of the truck.

Following the explosion, the State Mine Inspector recommended that no smoking be allowed by anyone handling explosives and that permissible explosives be used.

All the above accidents were avoidable and resulted from careless handling of explosives. It should be noted that several of these accidents occurred with pellet powder after the paraffin wrappers had been removed, thus destroying the one safety feature the pellet powder might have possessed. These relatively few instances of black-blasting-powder ignition by flame or heat could be multiplied severalfold.

Ignitions by Electrical Contacts

The preceding accidents showed the ready ignition of black blasting powder by flame, sparks, and heat; it also is readily ignited by an electric arc. Most of these accidents occur during transportation over mine tracks when the cars containing the explosives are hauled by electric trolley locomotives. An electrical conductor contacting a metal can or keg of powder may quickly burn through the keg and ignite the powder. Similar ignitions may occur when the negative current is short-circuited through the draw bar, bolts, or any metal part of a mine car and comes in contact with a metal powder keg. Electric arcs caused by dirty rails, broken bonds, or while sanding the track have ignited loose powder present on a mine car or truck.

The following accidents are cited as examples:

1. A keg of black blasting powder was exploded while being transported on top of a storage-battery locomotive. A portion of the battery cover was missing, and the keg rolled over onto the top of the exposed battery cells, causing a short circuit through the keg, which ignited the powder.

2. Ten kegs of granular black blasting powder were loaded on the 16th car of a 20-car trip to be transported through the mine a distance of about 2 miles to another opening, where it was to be used on grade construction work. The foreman stated that he instructed two employees to place the kegs in wooden boxes before placing them in the mine car; however, the kegs were placed on both sides of the car, which was of iron-reinforced wood construction, with the draw bar extending the length of the car. The explosion

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occurred when the trip was about 400 feet inby the portal. Examination at the place of accident revealed that bonds were cut from two rail joints on each side of the track, and two crossbonds were loose from the rail. Arcing and sparking were plainly evident when the cars passed these joints. It is apparent that the ignition of the powder was caused by the return current traveling through draw bars and couplings of the trip owing to the poor return circuit.

3. The premature explosion of two cases of pellet powder caused the death of one man and serious injury to two others. These men were members of crews who drill and blast the coal. A small wooden truck without ends or sides and hauled by a cable-reel locomotive was used to carry the electric drills, tools, pellet powder (in original wooden boxes), fuse, and paper dummy bags for stemming. At the time of the explosion, two of the men had just completed charging the holes in the face of an entry and were joined by a member of another crew. The explosion occurred as the controller on the cable-reel locomotive was opened. It is believed that an electric arc between the wheel and the rails, on which sand had been used, ignited a train of loose powder spilled on the side of the truck wheels and the floor from cartridges of powder that had broken preparatory to charging the holes in the entry.

The above accidents show the need of utmost precautions when transporting black blasting powder, particularly the granular type. Kegs of granular black blasting powder or individual powder cans and cases of pellet powder should be transported in specially designed insulated cars or in an insulated box to prevent the possibility of coming in contact with an electric conductor or possible short circuits.

Fires Caused by Black Blasting Powder

Black blasting powder has been and still is responsible for many fires. These fires were particularly numerous when granular black blasting powder was the chief explosive used for blasting coal, and there was little decrease in the number of fires until after permissible explosives began to displace black blasting powder. Fleming and Koster,4/ in discussing the problem of fires in Illinois coal mines in 1917, state:

"Furthermore, every mine in the district (Franklin County, Ill.) suffered from frequent fires from the use of black blasting powder, the coal igniting readily and there being some methane liberated at the face. At some mines as many as 25 fires occurred nightly following the firing of the shots, and in two instances 40 were reported. The employment of fire runners to follow the shot firers and extinguish fires became necessary. Four to ten men were employed for this work at each of the various mines, and the relatively small number of fires getting beyond control speaks well of the efficiency and carefulness of these men and of the officials."

4/ Fleming, J. R., and Koster, J. W., The Use of Permissible Explosives in the Coal Mines of Illinois: Bureau of Mines Bull. 137, 1917, p. 8.

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The operators and miners agreed upon an improvement in the method of using black blasting powder, but this did not prevent mine fires, which occurred at shot-firing time when black blasting powder was used by expert miners under stringent regulations. The introduction of permissible explosives resulted in a material decrease in the occurrence of mine fires caused during the shot-firing operation.

Some coals, particularly those with high volatile content, are more readily ignited by black blasting powder than others, but in many mines the gas released during blasting is ignited by the flames of black powder, which in turn ignites the coal. Squibs and fuse, when used to fire black blasting powder, greatly increase the possibility of fires and have been directly responsible for scores of fires in coal mines.

Although fires caused by explosives have been reduced in number considerably since the increased use of permissible explosives, fires continue to occur following blasting in mines with black blasting powder. The newer type of black blasting powder in pellet form is little different from the granular form in its capacity for starting fires, as the proportion of mine fires caused by pellet powder is about equal to that caused by the granular powder.

Loss of life and injuries from fires caused by explosives are relatively small in number, but property damage and economic loss are always great, and many mine fires ultimately result in explosions that take a heavy toll of life. Although most of the fires from explosives are discovered in the early stages and are easily smothered, the possibility exists that a fire may gain headway before it is discovered and may make it necessary to seal a considerable area of the mine or it may result in an explosion. The loss of production from a sealed area, cost of sealing and reopening it, and the dangers of fighting or sealing off a fire area are a great price to pay for the continued use of black blasting powder. This loss will continue to occur unless extra precautions are taken during and after the firing of shots in any coal mine.

The following examples of fires, all involving black blasting powder, show the ease with which these fires occurred and the dangers attending them:

1. A fire was discovered in the face of an entry by the fire boss about 4 a.m. This place had been blasted about 5 p.m. the previous evening, and the "shot runner" that followed the shot firer apparently failed to see the fire. The entries were sealed within 4 hours and were reopened 43 days later. This mine had changed from permissible explosives, fired electrically, to pellet powder, owing to the low price of fine sizes of coal and the desire to break more lump coal.

2. Face coal was ignited in a pillar during blasting with black pellet powder and squib. The fire was discovered 3 days later. Attempts to fight the fire were unsuccessful, and the fire area was sealed. This mine was classed as gassy, used electric cap lamps, permitted smoking, and blasted the coal off the solid with pellet powder and squibs. Fires were common in the mine, owing to the use of black blasting powder, and occurred on an average of once a month, not counting the fires found and extinguished by "fire runners."

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3. Black-blasting-powder shots were fired in a mine about 4:30 p.m., and the mine foreman inspected the mine immediately for possible fires, but the smoke was too dense to see relatively small fires. Six men entered the mine about 5 a.m. and did not discover that there was a fire until about 10 a.m. The fire had a good start, and it was necessary to seal the mine at the collars of the shafts.

4. While making a preshift examination, a fire boss discovered a fire in the face of a room off the main slope. Coal was blasted by granular black blasting powder and fuse by shot firers on the off shifts; shots were blasted in this room at 4 a.m. Fires occurred frequently because of gas released during blasting, and it was the general practice to extinguish the flames of the burning gas or the fire by shooting dynamite close to the fire. During attempts to fight the fire, several full kegs and partly filled kegs of black blasting powder were found in the vicinity of the fire and were known to be near the face of the room; this made direct methods of fighting the fire hazardous. The mine was flooded by pumping water down the slope.

5. A fire was discovered at the face of an entry by the mine manager before the shift entered the mine. Three shots of black blasting powder had been fired in the face of the entry, and it is believed the shots ignited a gas feeder. The coal was undercut and blasted with single F granular black blasting powder.

6. A miner loaded and fired a rib hole in an entry at the beginning of the shift. After waiting for about 10 minutes for the smoke to clear, he returned to the face and found the loose coal on fire; he had common knowledge of fires of this type and casually combatted it, but, after he loaded about 1-1/4 cars of coal, the flames, which were evidently gas-fed, caused him to retreat. The superintendent was notified, and he ordered all men out of the mine. The fire area was sealed and reopened about a month later.

There were 214 workers in the mine at the time of the fire. The coal was undercut and blasted with pellet powder by the miners any time during the shift. Carbide lights were used for illumination.

7. A fire was discovered in a small mine when the men reported for work. On the previous day, four holes, each charged with three sticks of pellet powder and stemmed with coal dust, were fired between 2 and 3 p.m. No fire run was made, and the fan was shut down. The fire was extinguished the day following its discovery.

8. A fire resulted from blasting coal with pellet powder in the face of a room and was responsible for five deaths. The fire apparently was started two nights previous to the day the deaths occurred and was evidently discovered by the fire boss on his preshift examination; however, the men were allowed to enter the mine. A man-trip with 12 men was pushed through smoke to within 70 feet of the fire; all of these escaped except one. Four men lost their lives in an adjacent entry from inhaling carbon monoxide from the fire.

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When mine officials were asked why men were allowed to enter the mine when a fire was known to be in one section, they replied that there had been several similar fires that had been extinguished or loaded out. The fire area was sealed.

Explosions Caused by Black Blasting Powder

The greatest potential danger in the use of black blasting powder in coal mines, particularly bituminous-coal mines, is the hazard of igniting coal dust in suspension or an air-gas mixture resulting in widespread explosions with great loss of life. These explosions have occurred and will continue to occur in coal mines where black blasting powder is used unless proper precautions are taken during the placing, charging, and firing cycle, and, even when available precautions are taken, fires and explosions are likely to occur when black blasting powder is used in coal mines. The record of mine explosions caused by explosives in the United States is one to which the coal-mining industry can point with little pride. Tables 1 and 2 of Bureau of Mines Information Circular 7004 show that explosives caused 620 explosions that killed 3,847 persons from the time records were available (for most of the States 1870-1880) to 1937. These tables show that explosions from this cause accounted for 27.7 percent of the deaths and 21.6 percent of the explosions for all causes during that period. From 1937 to July 1945 there have been 33 explosions due to blasting which caused 187 deaths, or about 18.3 percent of the deaths and 15.5 percent of the number of explosions from all causes. The severity of most of the explosions since 1937 is not high when it is considered that four major explosions were responsible for a total of 155 deaths, one of them, in 1940, resulting from a blown-out shot of black blasting powder and causing 72 deaths. The number of explosions cited above is by no means complete or accurate, particularly for the earlier years, as scores of explosions originating from blasting caused no deaths and slight property damage and probably were not reported. Even today, numerous local explosions due to using black blasting powder are not reported, especially in small mines.

Although danger exists in the use of any type of explosives in coal mines, the danger is much greater from black blasting powder than from other explosives because of its characteristic duration and length of the flame. Records and studies of explosions cuased by explosives show that nearly all these explosions have been caused by black blasting powder. Harrington and Howell, in Bureau of Mines Technical Paper 567, show in table 4, as compiled from data from the Bureau of Mines files, that 117 explosions which resulted in 1,136 deaths, occurred in United States coal mines from 1908 to 1932. Black blasting powder was involved in all but 27 of these explosions; 14 of these were caused by dynamite, and 13 by permissible explosives used in a nonpermissible manner. The explosions from permissible explosives occurred between 1924 to 1932, but several have occurred since 1932.

Before 1930, or before the decrease in its use, black blasting powder was responsible for the majority of all explosions in several States and in some sections of other States. Table 2 in Information Circular 7004 shows that explosives were responsible for between 50 to 75 percent of all explosions in some States.

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Blown-out and overcharged shots of black blasting powder have been one of the major causes of mine explosions. The records show that 422 of the total of 653 explosions caused by explosives to June 30, 1945, resulted from blown-out shots, all with black blasting powder. Apparently, many of these explosions were due to poor blasting practices and lack of precautions. In poorly stemmed shots, the flame of black blasting powder extends several feet from the hole, with the possibility of igniting any coal dust in suspension or an explosive gas-air mixture. The hazards are much greater when coal dust is used for stemming or when several shots are fired in rapid succession. It has been shown by experiments that as little as 1 to 1-1/2 percent of methane, an amount that is not readily detected by a flame safety lamp, greatly increases the explosibility of coal dust.

Blown-out or windy shots are likely to occur frequently when shooting off the solid, unless the hole is properly loaded and the burden or pull of the shot is not too great. Virtually all the mine explosions from black blasting powder in the past few years have resulted from blown-out shots. The same condition would be present in the case of an overcharged shot, as the coal falls before all the powder burns, and this may ignite coal dust or gas or a mixture of them. A properly charged shot may have the same effect as an overcharged shot in the presence of a slip, fault, partings, or soft material when any excess energy not required to break down the coal may be expended on the air, thus giving rise to a so-called windy shot.

A fallacy has existed for many years to the effect that black blasting powder can be used in nongassy mines but not in gassy mines. Several States have laws allowing the use of black blasting powder in nongassy mines but not in gassy mines. Several of the following examples have disproved this fallacy, as does an explosion that occurred nearly 50 years ago in a Western State when a dust explosion was caused by black blasting powder and took 200 lives. Before and subsequent to this explosion, explosive gas had never been detected anywhere in this mine, and it was a definite example that coal dust could initiate and also extend a widespread mine disaster.

Examples of Explosions Caused by Black Blasting Powder

1. A blown-out shot igniting coal dust thrown into suspension by three previous shots caused a coal-dust explosion that severely injured the two miners who had ignited the shots. Four holes spaced 4 feet apart were drilled almost straight into the face, charged with granular black blasting powder and fuse, and fired in rapid succession. The miners lit the shots and were just a short distance from the drift mouth when they heard the first, second, and third shots explode, and, after a short interval, they were enveloped in flame and blown along the entry.

2. A shot firer in a small coal mine was killed when a blown-out shot ignited coal dust and created an explosion that spread throughout the mine. The shot firer was blasting after the men left the mine and was using black pellet powder for shooting off the solid. Evidence showed that a badly placed shot in a room had partly blown out, and a succeeding shot was fired in a crosscut that was nearly through. This later shot blew through the crevices of the coal and ignited the dust in the adjacent room.

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3. A coal-dust explosion occurred in a mine that used black pellet powder for blasting the coal; 72 men were killed, 22 were overcome by blackdamp and were revived on the surface, 79 were imprisoned for 5 hours before being rescued uninjured, and 2 escaped uninjured. This mine undercut all the coal, and shot firers blasted the coal any time during the shift. The powder was ignited by electric squibs, and holes were stemmed with bug dust in paper dummies and tamped with copper-tipped steel bars. Pellet powder in original containers was taken into the mine 2 days a week and stored in steel boxes holding 500 to 600 pounds.

There was a difference of opinion in the various agencies investigating the explosion as to the initial cause, but all agreed that black pellet powder was involved. The Bureau of Mines investigators believed the explosion was caused by a blown-out shot that was overcharged and stemmed with bug dust.

4. An ignition of coal dust severely burned a miner after he fired a shot of black pellet powder at the face of a heading. The flame of the explosion was propagated a short distance from the point of ignition and was stopped by rock dust, the heading having been rock-dusted by machine to the last crosscut and heavily hand-dusted to the face. Previous to the ignition, two shots had been fired in the face of the heading, the first charged with 2-1/2 sticks of pellet powder and the second, 17 inches below, charged with 2 sticks. Both holes failed to do their work. The miner then made another hole 49 inches deep and charged it with 4 sticks, or 32 inches, of powder, which, when fired, ignited the coal dust. Shots were ignited with electric squibs, but it is apparent this hole was overcharged. At the time of the explosion the company was planning to change to the use of permissible explosives for blasting within a few weeks. There were 260 men in the mine at the time of the explosion; many were saved through the thorough application of rock dust on the surfaces of the mine workings.

5. Twenty-three men were killed by a coal-dust explosion created by a blown-out shot or shots that had been drilled in a crosscut. The coal in the crosscut was shot from the solid. (All other places were undercut.) The first shot had been drilled within 14 inches of the adjoining room and probably broke through; this threw considerable coal dust into suspension and also probably partly exposed the explosives in the second hole. When the second hole was fired, it expended its force largely into the air and undoubtedly ignited the dust thrown into suspension by the fire shot.

The electric equipment in the mine was of permissible type; the coal was undercut; carbide lights were used; pellet powder, stemmed generally with clay, was used for blasting; and gas was never detected in the mine. The shots were normally fired by shot firers on the off shift, but the above two shots were fired by the miners while the shift was in the mine, and coal dust was used for stemming.

6. Gas and coal dust were ignited by a blown-out charge of pellet powder in a hole drilled and shot off the solid in a narrow pillar and severely burned four men. The explosion was localized, as the affected area had been thoroughly rock-dusted. Two holes, one on each side of a 6-foot pillar

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between room necks, had been drilled almost opposite each other, one slightly higher than the other, with the bottom of each hole ending about 1 to 1-1/2 feet from the opposite rib. The shot firer examined the one room neck for gas and, not finding any, charged and fired the hole; but he did not examine the other room neck. The shot blew through the pillar into the adjacent room and ignited gas and coal dust and caused a local explosion. The coal in the section where the explosion occurred was shot off the solid by pellet powder fired electrically; the coal in the other sections of the mine was undercut and blasted by permissible explosives fired electrically. The mine was classed as gassy, and gas had been reported in the section where the explosion occurred. The other 90 men in the mine at the time of the explosion escaped unassisted.

7. Two night bosses, the only men in the mine, were killed when blown-out shots of black blasting powder ignited coal dust. Main entry and chain pillars were being extracted in this mine and had been extracted to within a few hundred feet of the shaft bottom. The coal was undercut and shot with black blasting powder and fuse by shot firers after the men left the mine. The night shift was idle on the night of the explosion, and the two bosses were taking care of pumps and such other work as they could do.

The mine foreman stated that on the previous day three tight shots had blown the tamping without apparently breaking any coal. The foreman believed that the night bosses loaded these same three holes, and the shots again blew out. Doubtless, this surmise was correct, as the two men had signaled the engineer for the cage, and as the engineer gave the return signal the explosion occurred. It apparently had been the intention of these men to light the shots and get on top before the shots fired, but they evidently miscalculated the burning rate of the fuse.

8. A shot firer was killed by a dust explosion while firing shots about 5 a.m., his body being found by the day-shift crew. The coal was undercut by a compressed-air mining machine, and only a small amount of explosive per hole was required to break the coal. Black blasting powder with fuse ignited by an open light was used for blasting the coal.

The explosion occurred in a room where the miner had drilled two holes. He drilled a 5-foot hole about 12 inches from the rib and roof and evidently decided the hole was too low; he then drilled another about 7 inches above the first one. The shot firer charged the top hole with a stick of pellet powder 1-14 inches by 6 inches but failed to plug or stem the first hole. The charge evidently blew out through the lower hole and ignited the dust in the hole as well as the dust in the vicinity of the shot.

9. A local coal-dust explosion was caused by granular black blasting powder in a small mine. The foreman and three men in the mine at the time were unaware of the explosion. The coal was blasted off the solid by black granular powder, ignited by fuse, and stemmed with fine coal dust. One of the miners loaded four holes each with 4 pounds of granular black blasting powder, using coal dust for stemming. He lighted the fuse and left the mine. The next morning a fire was discovered at the face of the place, and evidence of an explosion was found.

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Precautions for Using Black Blasting Powder

The Bureau of Mines, from its studies and investigations of disasters, has found that black blasting powder is unsafe for use in coal mines and has but one general rule regarding its use: Don't use black blasting powder. However, realizing that for various reasons black blasting powder is being used and undoubtedly will be used for many years, engineers of the Bureau of Mines feel that it can be of service by outlining the least dangerous methods of handling it and by suggesting some precautions that will lessen many of the hazards arising from its use.

The formulation of rules or precautions for the safe use of black blasting powder to cover every mine would be impossible because of the difference in working conditions, mining methods, and types of workers; however, an outline of general precautions based both on lessons learned from the above-given examples of accidents as well as scores, probably hundreds, of others, and on improved safety practices, should be beneficial to present users of black blasting powder. Although some of the following precautions may seem like "old stuff" to many readers, nevertheless, it has been found that disregard of the simple, fundamental precautions, together with carelessness and thoughtlessness, has been the greatest cause of scores of explosives accidents, many of which resulted in widespread disaster.

Type to Use

1. Pellet or stick black blasting powder should be used in preference to the granular or loose type for coal-mine blasting.

The chemical and physical characteristics of granular and pellet powder are similar, but the pellet or stick type is, to some extent, at least, less dangerous to handle and more convenient to load. The wrapped cartridges and the wooden cases in which the cartridges are packed minimize the hazards of transportation and handling; also, the pellet type removes to some extent the handling of loose powder and the making up and filling of cartridges, with the ever-present danger of spillage. The danger of opening the metal keg and the possibility of spillage from a damaged or broken keg also are removed.

Several of the above-described accidents would probably have been prevented by the use of pellet powder rather than granular black blasting powder.

Storage and Transportation

1. Black blasting powder should be stored in permanent magazines that are theft-resistant and fire-resistant, but they need not be bullet-resistant. The magazine should be dry, well-ventilated, and have natural light. The floors should be of wood or other nonsparking material that also presents no hazard from friction. Metal magazines should be lined with a nonsparking and friction-proof material and be grounded. Also, magazines covered with sheet iron should be grounded. For amounts not exceeding 125 pounds, the powder may be stored in box-type magazines. Under no circumstances should

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the powder be stored in or near any part of a store, dwelling, outhouse, chicken coop, or similar structure, or near any inhabited structure, or railroad, or other public facility that handles passengers.

Powder should not be transported in an open car. For transporting into the mines, the powder should be in a specially designed insulated car or in a separate insulated box or boxes; preferably, the black blasting powder should be taken into the mine when the power is off; but when hauled by trolley locomotive the powder car should be insulated from the rest of the trip. Trucks or cars used by shot firers should have special compartments that contain the powder.

2. Powder sufficient for one day should should be distributed to each working place.

3. Where powder is stored in the mine for underground distribution, only a supply sufficient for 1 day should be stored.

4. In mines where the miners carry in their own powder, well-constructed storage boxes placed at least 100 feet from the face should be used for storing the powder.

5. Men carrying black blasting powder should not be allowed on man-trips, and powder cars should not be hauled by man-trips.

The above precautions are meant primarily for pellet or stick powder, but as granular powder is still being used, additional precautions are required for its safe handling.

There is only one safe and proper way of opening a metal keg or granular powder, viz., by prying up the four metal clips on the bung with a sharpened wooden stick and removing the metal cap and underlying paper washer with the fingers.

A metal keg of black blasting powder should never be opened by punching a hole in it with a pick, metal object, or any other device such as a wooden pin, wooden wedge, or sharpened piece of wood struck by a wooden mallet. The powder should be poured only from the bung hole. There are numerous instances of explosions caused by making an opening in the keg with a pick, wooden devices, and so-called nonsparking tools. Records are available of some explosions that show that explosions resulted from attempting to open metal kegs of powder with wooden wedges, wooden pins, or sharpened pick or axe handles and wooden mallets.

Miners should not be allowed to take full kegs or partly full kegs of powder underground. The powder should be carried underground in rustproof and moistureproof canisters or jacks, preferably of nonmetallic and friction-proof material, in quantities sufficient for only one day's use. The canisters, jacks, or containers should be stored underground in wooden boxes placed at least 100 feet from the face or working place.

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Essentially the same precautions should apply to the storage and transportation of granular powder.

Smoking or open lights should not be permitted while any kind of explosive is being handled or in the vicinity where explosives are stored or used, and this applies more definitely to black blasting powder than to other types of explosives.

Placing and Charging Holes

Most of the accidents involving black blasting powder have resulted from poor placement of holes and unsuitable procedure in the loading or firing of holes.

1. All shots should be fired by instantaneous electric squibs by employing electric blasting units.

2. Fuse or sulfur or gas squibs should not be used for firing shots.

Electric squibs are safer than either fuse or ordinary squibs; they permit the miner to control firing from a safe distance, allow more complete confinement of the charge, reduce hang-fires and the danger of misfires, and produce less smoke and toxic fumes.

3. If possible, coal dust in the vicinity of the shot should be wetted down before blasting.

4. The mine should be adequately rock-dusted, and rock dust should be scattered heavily in the vicinity of the shot.

The advantages of adequate rock dusting were well illustrated in some of the examples of explosions given previously in this publication.

5. Examinations for gas should be made before charging and firing any shot or shots.

6. Shots should be fired only by certified or qualified shot firers on the off shift or when all other persons are out of the mine.

7. Holes should be examined and charged by shot firers.

8. A fire runner or some other official should examine the mine for fires as soon as an examination can be made safely.

9. Only incombustible material, such as moist clay, adobe, limestone, or shale, should be used for stemming, which should be tamped solidly to the collar of the hole. Coal dust, cuttings, or other combustible material should not be used for stemming.

10. Only wooden tamping bars should be used; iron or steel tamping bars or metal-tipped bars should not be used.

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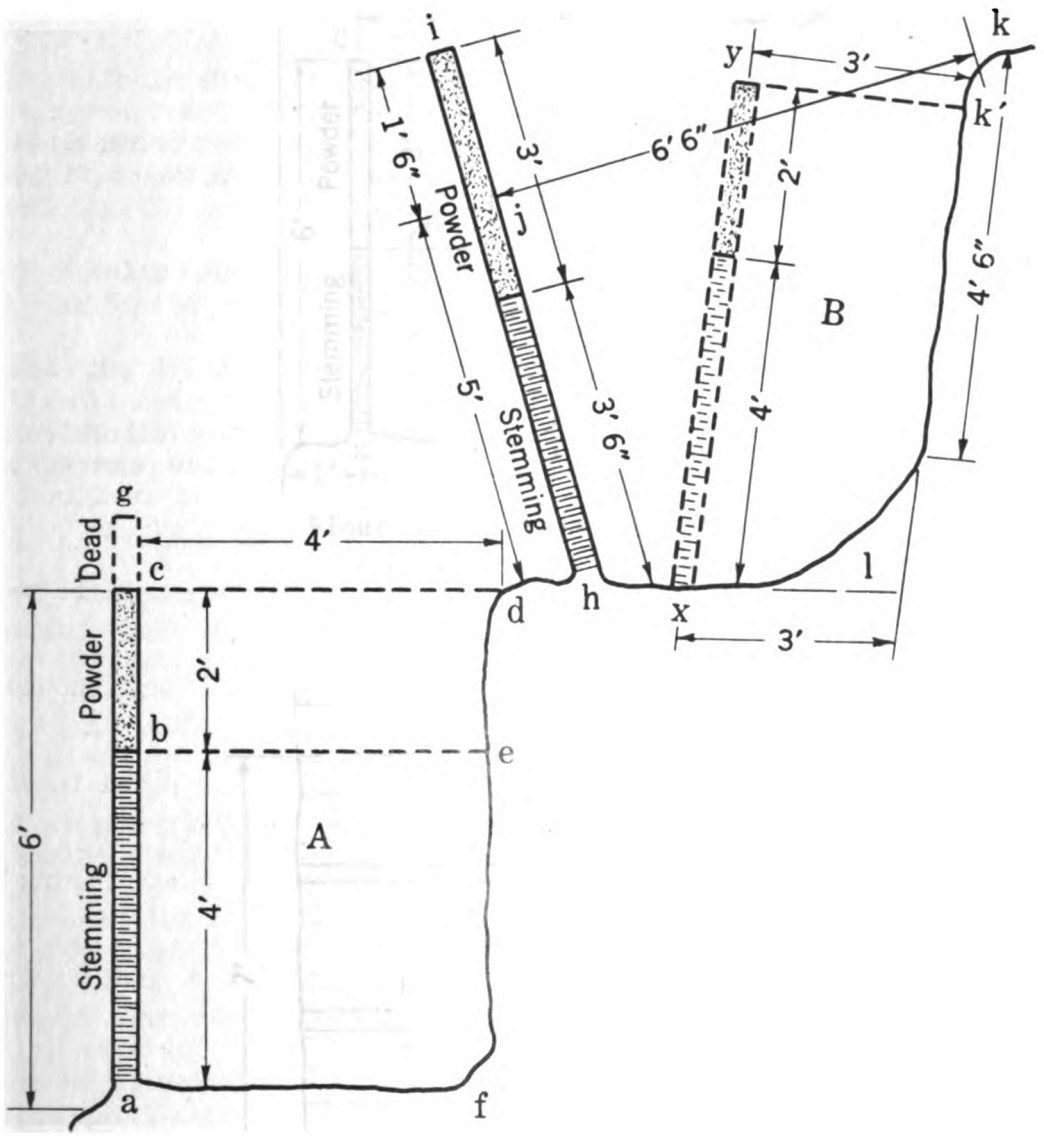

Figure 1. - Shothole (AG) with dead end, CG; a dangerous shot, HI; a properly placed shot, XY.

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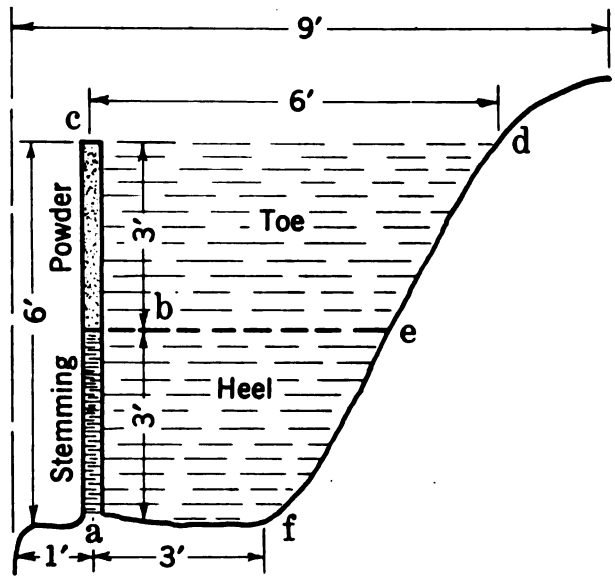

Figure 2A. - Plan view of a poorly balanced shot.

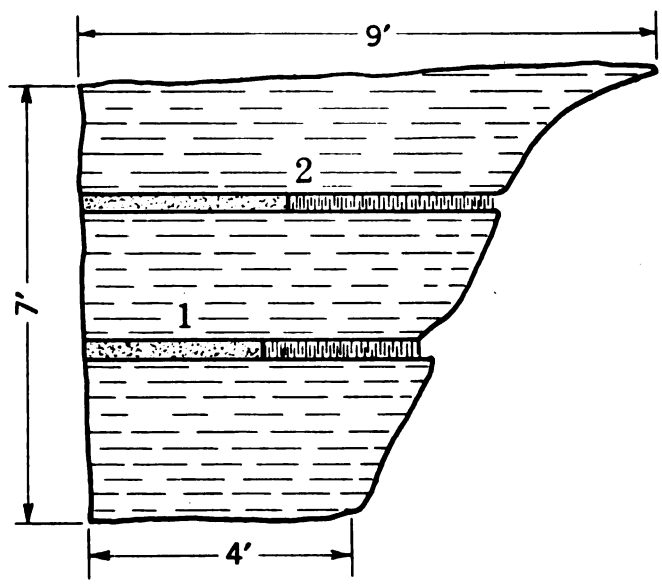

Figure 2B. - Safe method of shooting place as shown in figure 2A.

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11. Shots should be charged and fired singly and not in rapid succession; to fire several shots simultaneously is safer practice than firing several shots in quick succession.

12. In mines where coal is undercut, the inside end of the borehole should be at least 6 inches outside the innermost depth of the cut.

13. Coal cuttings should be well-cleaned from hole before charging.

14. A hole should never be drilled in or near the portion remaining after a former shot, near cracks, soft partings, or crevices, or in badly crushed or fractured coal. Danger exists in shots of this type from the flame of the powder and hot powder gases escaping through cracks or otherwise and igniting coal dust or gas-air mixtures or combinations of them.

15. Holes near the rib should be drilled parallel to the rib or as nearly so as possible to prevent "gripping" shots.

16. The drill holes should be drilled in such a way that the shot will be well-balanced, according to the amount of material to be moved, and good judgment should be used in charging all holes (see figs. 1, 2A, and 2B) to try to prevent their being either undercharged or overcharged.

Duties of the Shot Firer

The shot firer should examine all holes before they are charged, and if he has any doubt as to the safety of the placement of the hole, he should not load or fire it.

It is usually dangerous to try to charge and fire a hole a second time after the charge has missed or failed.

A gripping hole should be examined carefully; in general, these holes are dangerous and should not be fired.

Care should be taken to make sure that a hole or shot that is dependent is not fired until the first shot is fired and breaks an opening.

Particular care should be taken of shots in tight holes, such as at the mouth of entries, room necks, crosscuts, and in break-throughs near face of entries or between rooms.

A hole drilled near a parting or soft streak in the coal seam should be examined carefully before charging.

The following sketches show suitable methods of placing holes for minimizing the hazards of blasting while also showing poorly placed holes and what to avoid in gaging a hole for safe blasting.

An understanding of the following terms or definitions and thier application to the placement and charging of boreholes should be helpful in reducing the number of blown-out, windy, and gripping shots with the ever-present danger of explosions.

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Dead hole. - A hole that extends into the solid coal beyond the point from which the coal or rock can break from a loose end or open face. In undercut coal it is that portion of the hole beyond the undercut. Hole AG, figure 1, shows a hole with a dead end (CG). In hole HI the portion JI is a dead hole.

Heel. - The heel is that part of the shot occupied by the tamping or that part of the coal bed to be moved (ABEF, fig. 1) that is back of the charge. Often the back end of the shot is called the heal of the shot, as the distance AF in figures 1 and 2 and HL in figure 1.

Toe. - That part of the shot or coal bed to be moved from the outer end of the powder to the front end of the hole. (BCDE, fig. 1.) The distance CD is often called the toe of the shot.

Chance. - The place to which a shot can break; the distance FD in figures 1 and 2 is the "chance" of the shot.

Line of least resistance. - This is a straight line drawn from the charge to the nearest free or open face of the material being blasted. Experience has shown that the best results are obtained when this line is essentially at right angles to the drill hole. The line of least resistance should be shorter than the length of the drill hole; if the line of least resistance is greater than the length of the drill hole, the powder probably will expend its force in the direction of the drill hole and fail to do any work. In figures 1 and 2 the line from C to D and in figure 1 the line from K to J represents the line of least resistance.

Well-balanced shot. - A shot is well-balanced when the line of least resistance is much shorter than the length of the drill hole and the toe and the heel of the shot have about the same width.

Quantity of powder to be used. - For safe shooting, the quantity of explosives in a hole should bear a fairly definite relationship to the quantity of stemming; generally, more stemming than powder should be used, and a good margin of safety is to have one-third more stemming than powder.

Poorly Balanced Shots

Figure 2 shows a dangerous shot. It may bring down the coal and yet produce a "windy" shot. The toe and heel should be of essentially the same width, and the length should be in proportion to the width of the shot (CD). Neither the toe nor the heel should be wider than the height of the coal bed. If the toe is narrow and the heel wide, the shot will be likely to blow out the toe and may ignite gas or dust in the air.

In shooting off the solid, the length and the width should bear a certain relationship. If the toe is much heavier than the heel, the blast may cause an explosion by blowing off the heel. But if the toe is much lighter than the heel, a blown-out shot may occur (and often does) even when the coal is undercut. Experienced miners undercut a heavy heel in order to balance a light toe.

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The width of the shot in shooting off the solid (CD in fig. 1) in coal beds 6 feet or less in height should not be greater than the thickness of the coal nor more than 5 feet at the most and should not be more than 5 feet in beds over 6 feet thick. A shot measuring more across the point than the height of the coal to be removed is generally dangerous. Horizontal holes parallel with the partings in the coal or those in soft streaks of coal or shale are likely to prove unsafe.

An unsafe and unbalanced shot is illustrated in figure 1 by the hole HI. This shot is unsafe for the following reasons: (1) The hole is drilled in a direction away from the loose end or in such a way as to grip the rib, causing a "gripping shot." It is not parallel to the loose end or free face KH. (2) There is almost as much powder as stemming. (3) The shot is much wider across the toe (front part of shot) than across the heel. (4) The line of least resistance is as long as the drill hole and is not at right angles to the charge. (5) This charge is dead for a distance of 1-1/2 feet (JI).

This type of shot is always dangerous, as there is a possibility of the powder blowing out the drill hole and expending its force on the mine air, as too much work was put on the powder. Shots of this type have caused many mine explosions. The holes are improperly placed, and generally the holes are overcharged in order to overcome the poor placement of the drill hole.

Hole AC, figure 2, is a plan view of a poorly balanced shot. The line of least resistance, CD, is as long as the drill hole, and the toe of the shot is much greater than the heel. Also, in charging this hole, as much powder as stemming was used.

Well-balanced Shots

A safe, well-balanced shot is one so laid out that there is every reason to believe that the powder will expend its force on the coal and not on the mine air. Figure 1 shows a well-balanced shot with drill hole AC. The length of the hole is 6 feet, whereas the width of the shot is 4 feet and, in accordance with safe practice, the quantity of powder used is less than the quantity of stemming, whereas the line of least resistance, CD, is at right angles to the charge and 2 feet shorter than the drill hole. However, should the hole be extended to G, the portion CG would be "dead," and a different set of conditions would be present, with the possibility of a blown-out shot.

Hole XY, shown in dotted lines on figure 1, is also a well-balanced shot and is properly charged. This shot should be used for blasting B of the sketch.

The coal to be shot in figure 2A can be shot safely by placing the holes as shown in figure 2B, with shot 1 fired first, followed by shot 2. It is much safer, and in many instances not much more powder will be used, if more holes are drilled and smaller charges are used than if an attempt is made to blast a heavy shot with only one hole.

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